Optimizing observation networks

combining ships of opportunity, Gliders, moored buoys and FerryBox in the Bay of Biscay and English Channel

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Objectives

Assess the performances of various existing and highly time-varying *in situ* networks in the Bay of Biscay and the English Channel (Fig.1), namely (a) RECOPESCA (Fig.2 - Leblond *et al.* 2010) based on opportunity fishing vessels with fishing nets instrumented using Temperature and Salinity sensors; (b) Gliders endurance lines ; (c) Ferrybox lines and (d) fixed mooring.

Provide first conclusions regarding the optimization of these networks, using the **low computational cost ArM methodology** (Le Hénaff *et al.*, 2009 ; Lamouroux *et al.*, 2015; Charria *et al.*, 2015)

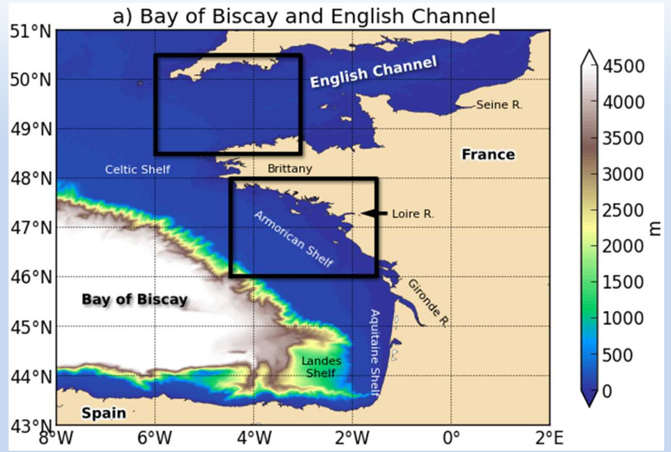

Fig. 1: Bathymetry (m) of the Bay of Biscay and the English Channel

Theory

Question: how can we characterize the performance of an observational array as defined by (H, $\mathbf{R}$) in such a way that we can compare the performance of one array to another?

H: observation operator
$\mathbf{R}$: obs. error cov. matrix

Innovation vector and associated second-order statistics:

$$\mathbf{x}^f = \mathbf{x}^t + \eta$$

$$\mathbf{d} \equiv \mathbf{y}^o - \mathbf{y}^f = \mathbf{y}^o - H(\mathbf{x}^f) \approx \varepsilon - \mathbf{H}\eta$$

$$\mathbf{y}^o = H(\mathbf{x}^t) + \varepsilon$$

$$\langle \mathbf{d}\mathbf{d}^T \rangle = \mathbf{R} + \mathbf{H}\mathbf{P}^f\mathbf{H}^T$$

$\mathbf{P}^f$: Prior (model) Error Cov. matrix

Intuitive global performance criterion:

If $\mathbf{R} >> \mathbf{H}.\mathbf{P}^f.\mathbf{H}^T$ ➔ obs./model discrepancies ≈ observational errors ➔ obs. not very useful

If $\mathbf{H}.\mathbf{P}^f.\mathbf{H}^T >> \mathbf{R}$ ➔ obs./model discrepancies ≈ prior state error ➔ obs. can be expected to be useful at identifying and correcting the prior state errors.

Formalized criterion

Scale the innovation vector second-order statistics by **R:**

$$\mathbf{R}^{-1/2}\langle \mathbf{d}\mathbf{d}^T \rangle \mathbf{R}^{-1/2} = \mathrm{I} + \chi \quad \text{with } \chi = \mathbf{R}^{-1/2}\mathbf{H}\mathbf{P}^f\mathbf{H}^T\mathbf{R}^{-1/2} = \mu\sigma\mu^T$$

1. Compare eigenspectrum $\boldsymbol{\sigma}$ to **I**, *i.e.* **count eigenvalues above 1**
2. Corresponding **array modes** $\boldsymbol{\mu}$: the "detectable" error modes above the obs. noise floor
3. Corresponding **Modal Representers:** $\rho_\mu = \mathbf{P}^f\mathbf{H}^T\mathbf{R}^{-1/2}\mu$ project array modes onto the physical space ≈ theoretical correction which would be applied by a particular array mode

Stochastic formulation

Use ensemble **A**:

$$\hat{\mathbf{P}}^f = \frac{1}{m-1}\mathbf{A}^f\mathbf{A}^{fT}$$

$$\hat{\chi} = \frac{1}{m-1}(\mathbf{R}^{-1/2}\mathbf{H}\mathbf{A}^f)(\mathbf{R}^{-1/2}\mathbf{H}\mathbf{A}^f)^T = \mathbf{S}\mathbf{S}^T$$

$$\mathbf{S} = \frac{1}{\sqrt{m-1}}\mathbf{R}^{-1/2}\mathbf{H}\mathbf{A}^f$$

$$\hat{\boldsymbol{\rho}}_\mu = \frac{1}{\sqrt{m-1}}\mathbf{A}\mathbf{S}^T\hat{\boldsymbol{\mu}}$$

Model & Ensemble

Model	MARS3D
Resolution	4km
Vertical levels	40 σ-layers
Period	May 3rd to 25th

Number of members	50
Perturbations	Atmospheric forcing: P, 10m-wind, Surface Heat Fluxes, T2m
	Bottom friction coefficient, turbulent-closure coefficient, light-extinction coefficient

References

Charria G., J. Lamouroux, P. De Mey (2015). Optimizing observation networks using gliders, moored buoys and FerryBox in the Bay of Biscay and English Channel. Submitted to Journal of Marine Systems.

Lamouroux J., G. Charria, P. De Mey, S. Raynaud, C. Heyraud, P. Craneguy, F. Dumas, M. Le Hénaff (2015). Assessment of RECOPESCA network contribution for the monitoring of 3D coastal model errors in the Bay of Biscay and the English Channel. Submitted in revised form to Ocean Dynamics.

Leblond E., P. Lazure, M. Laurans, C. Rioual P. Woerther, L. Quemener, P. Berthou (2010). RECOPESCA: a new example of participative approach to collect in-situ environmental and fisheries data: Joint Coriolis–Mercator Ocean Quarterly Newsletter. 37.

Le Hénaff M., P. De Mey, P. Marsaleix (2009). Assessment of observational networks with the Representer Matrix Spectra method – Application to a 3D coastal model of the Bay of Biscay. Ocean Dynamics. doi:10.1007/s10236-008-0144-7.

Arrays

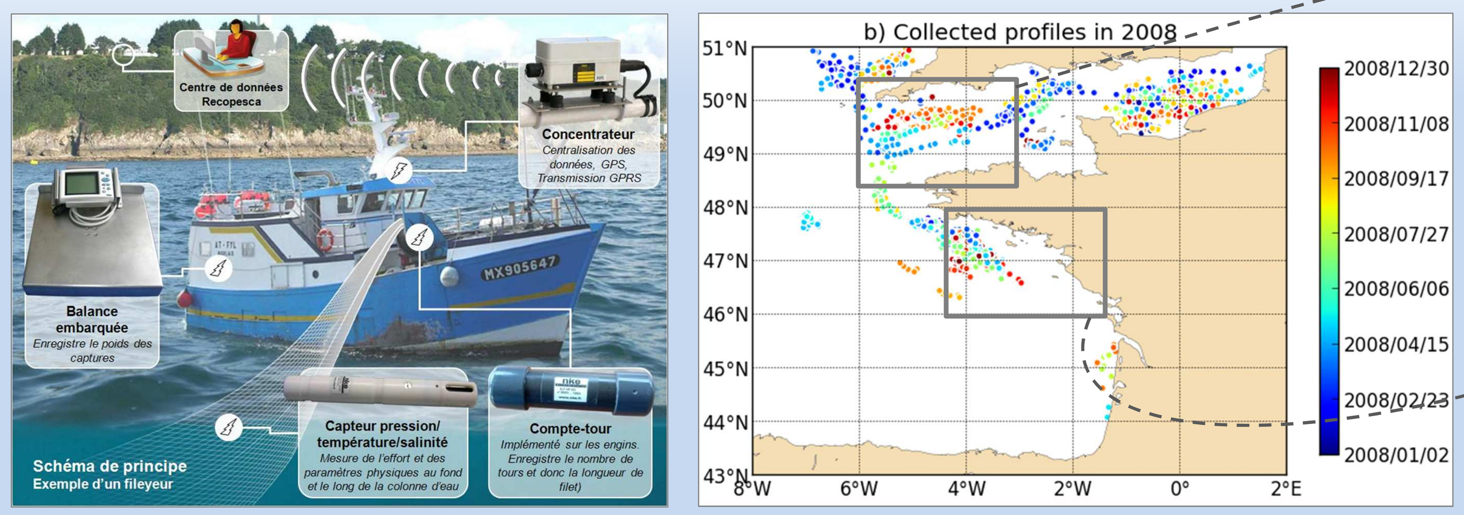

Fig. 2: RECOPESCA principle and 2008 space-time coverage

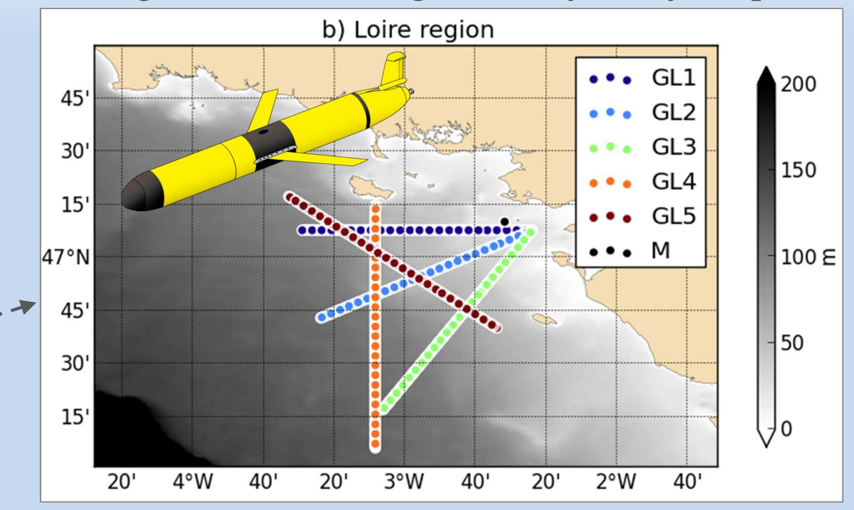

Fig. 3: Glider sections scenarios + Moored buoy (background: Loire region bathymetry map)

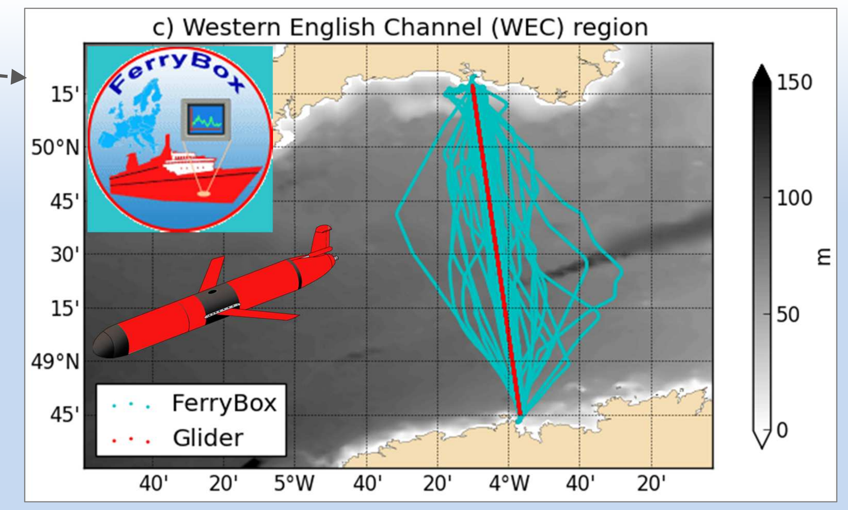

Fig. 4: Ferrybox transects and Glider section (background: English Channel bathymetry map)

Application #1: RECOPESCA (T profiles only ; T error=0.3°C)

Reference network

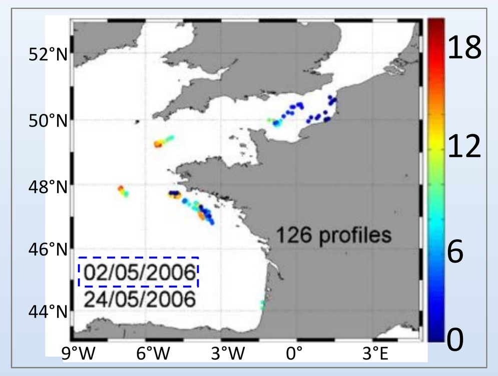

Fig. 5: Reference network – unit=elapsed days since 02/05/2006

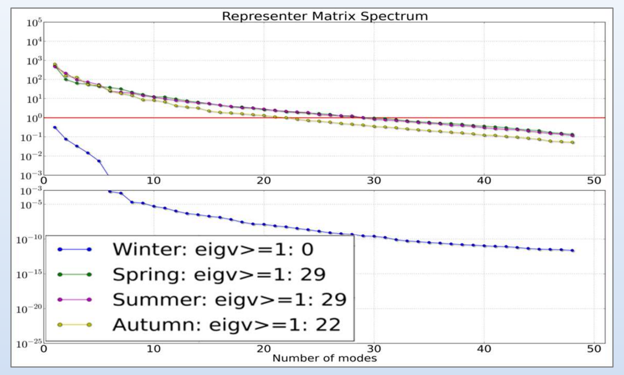

Fig. 6: Eigenspectrum $\boldsymbol{\sigma}$ of χ relative to four periods of study

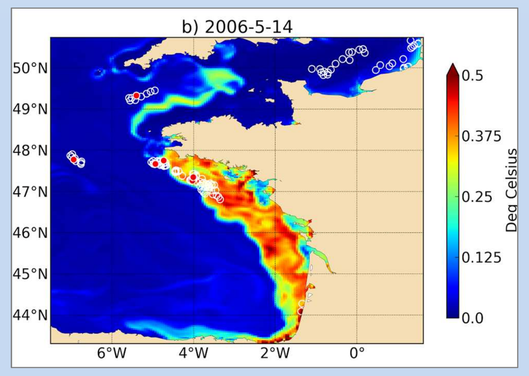

Fig. 7: SST Ensemble std.dev. (proxy for SST model error) - 14/05/2006 – unit=°C

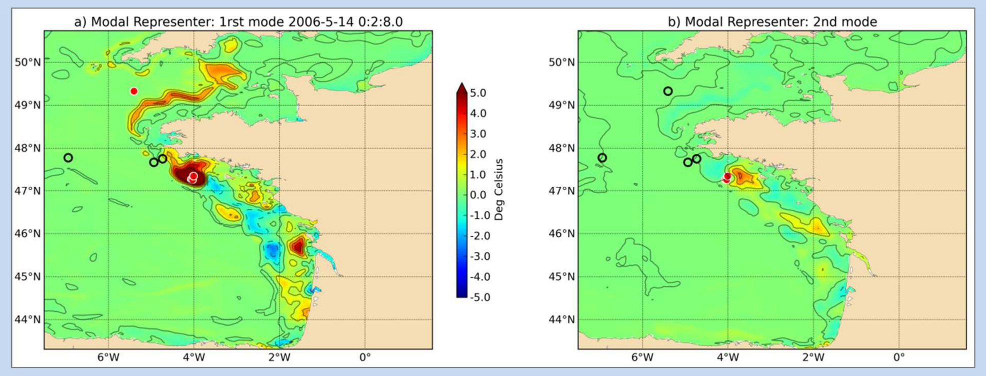

Fig. 8: 1st and 2nd SST modal representers $\boldsymbol{\rho}_\mu$ - 14/05/2006 - – unit=°C – black circles=profiles at date – red spots=modal profiles $\boldsymbol{\mu}_{MP}$ at date. NB: ∃ z ; $\boldsymbol{\mu}_{MP}(z) \geq$ std.dev($\boldsymbol{\mu}$)

Extension scenarios

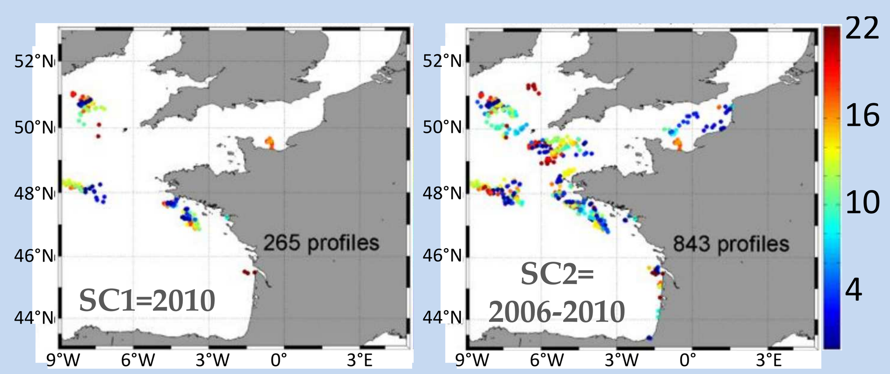

Fig. 9: Extension scenarios SC1, SC2 – unit=elapsed days since 02/05/2006

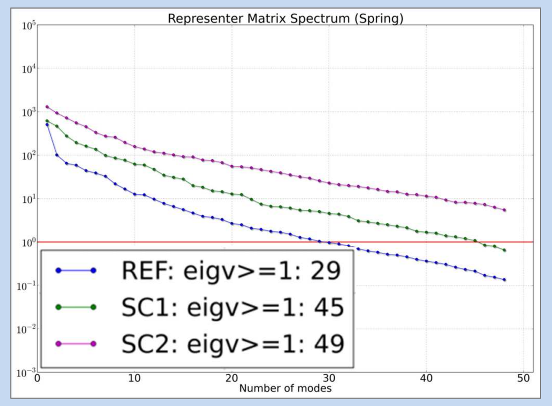

Fig. 10: Eigenspectrum $\boldsymbol{\sigma}$ of χ relative to the three networks

➔ **Extensions scenarios provide a better capture and description of the model error subspace variability modes**

➔ **But increasing the number of profiles does not necessarily result in greater efficiency (SC1<REF<SC2)**

Efficiency	REF	SC1	SC2
winter	--	0.03	0.09
spring	0.23	0.11	0.24
summer	0.20	0.19	0.20
autumn	0.20	0.10	0.15

Table 1: Efficiency indicator e_f for the three networks: $e_f = \frac{nb(\mu_{MP})}{nb(profiles)}$

Application #2: Gliders / Buoy / Ferrybox

(T and S obs. ; T error=0.3°C, S error=0.25)

Glider / Buoy networks

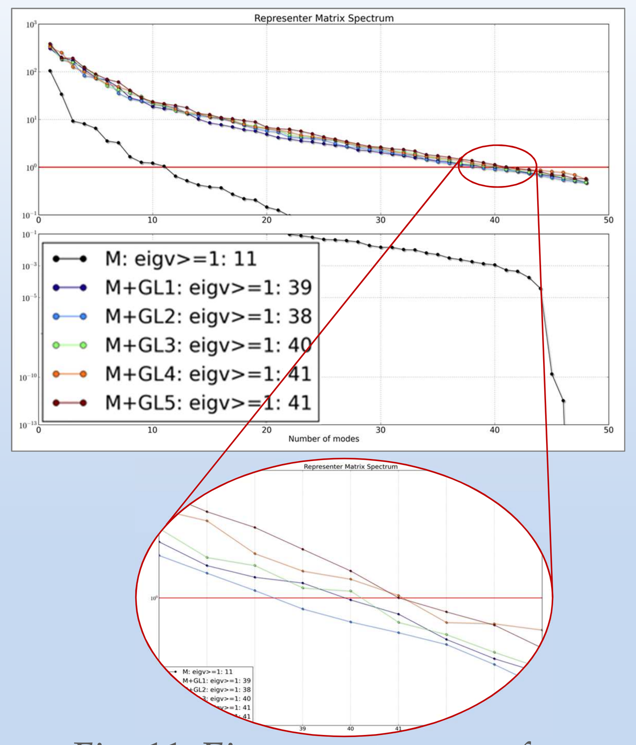

Fig. 11: Eigenspectrum $\boldsymbol{\sigma}$ of χ relative to the Mooring/Glider sections

➔ **A**long-shore and meridional glider sections (GL4, GL5): more efficient sampling of model uncertainties than the cross-shore design (GL1,2,3)

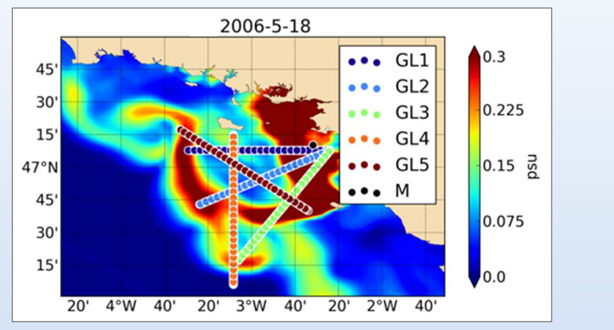

Fig. 12: SSS Ensemble std.dev. (proxy for SSS model error) - 18/05/2006

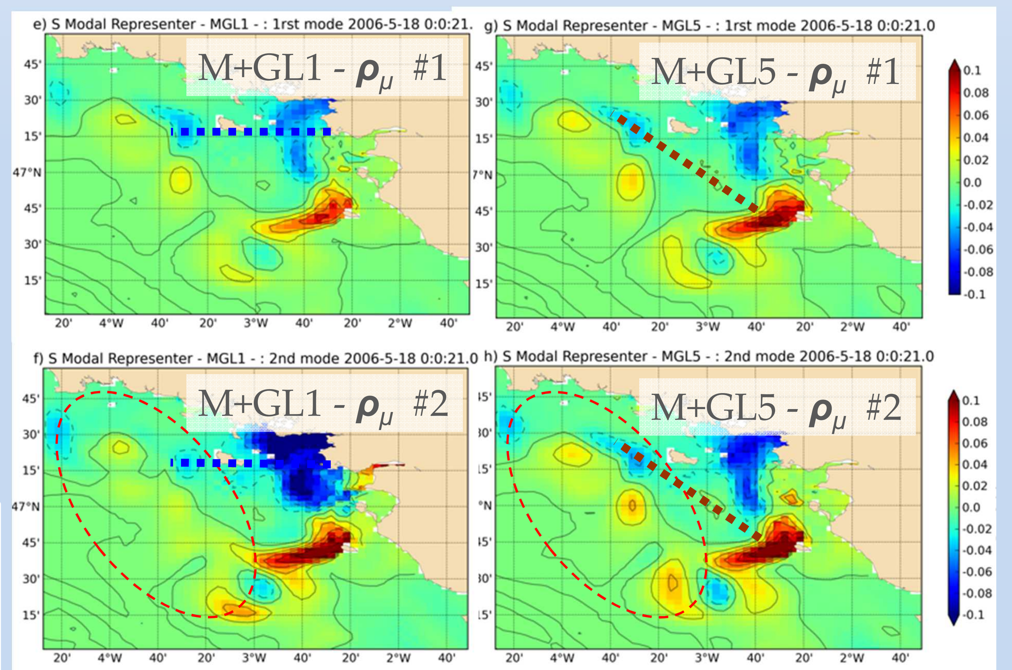

Fig. 13: 1st and 2nd SSS modal representers $\boldsymbol{\rho}_\mu$ of Mooring/Gliders configurations 1 and 5 - 18/05/2006

Glider / Ferrybox networks

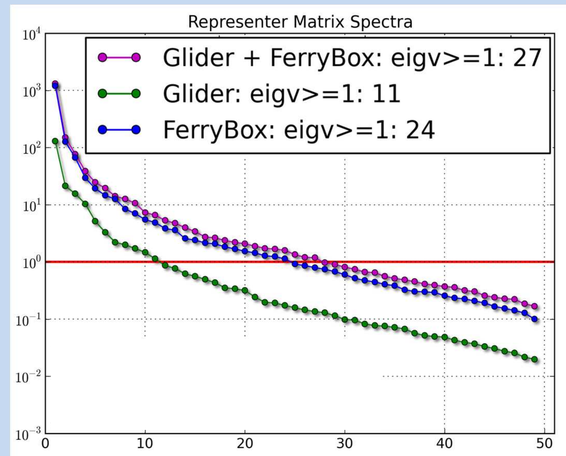

Fig. 14: eigenspectrum $\boldsymbol{\sigma}$ of χ relative to the Glider/Ferrybox arrays

➔ Efficiency of the fast-sampling FerryBox line to monitor the strong tide dynamics/errors

➔ Limited enhancement brought by the glider as a complementary sensor

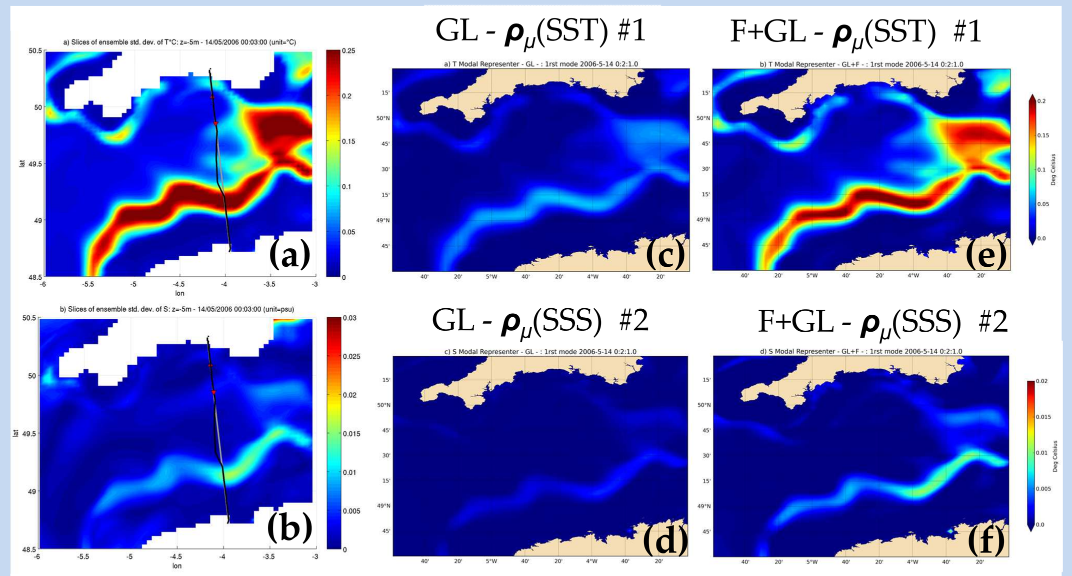

Fig. 15: (a) SST and (b) SSS Ensemble std.dev. 1st and 2nd modal representers $\boldsymbol{\rho}_\mu$ of (c,e) SST and (d,f) SSS for the Glider/Ferrybox configurations - 14/05/2006